

# Intake, digestibility and nitrogen utilization of three tropical tree legumes II. As protein supplements

Roger C. Merkel<sup>a,\*</sup>, Kevin R. Pond<sup>b</sup>, Joseph C. Burns<sup>c</sup>,  
Dwight S. Fisher<sup>d</sup>

<sup>a</sup>Small Ruminant Collaborative Research Support Program, North Sumatra, Indonesia/Winrock International,  
Route 3, Petit Jean Mountain, Morrilton, AR 72110, USA

<sup>b</sup>Department of Animal Science and Food Technology, Texas Tech University, Lubbock, TX 79409-2141, USA

<sup>c</sup>USDA-ARS and Department of Crop Science and Animal Science, North Carolina State University,  
Raleigh, NC 27695-7620, USA

<sup>d</sup>USDA-ARS, J.P. Campbell Sr. Natural Resource Conservation Center, Watkinsville, GA 30677-2373, USA

Received 3 July 1997; received in revised form 16 April 1998; accepted 28 April 1999

## Abstract

*Calliandra calothyrsus*, *Paraserianthes falcata* and *Gliricidia sepium* leaves were supplemented at both 25 and 50% of dietary crude protein to a basal concentrate and fed to growing ram lambs. A control diet consisted of concentrate and the forage grass *Brachiaria brizantha*. Dry matter intakes and ADG of tree legume supplemented treatments were lower ( $P < 0.05$ ) than control lambs, but increasing the amount of tree leaves fed did not result in further decreases in either dry matter intake or ADG. Dry matter digestibility was lower ( $P < 0.05$ ) in both 25 and 50% dietary treatments compared with the control, while NDF digestibility was lower ( $P < 0.001$ ) only in the 50% dietary treatments. Increasing the amount of leaves fed from all three tree species, led to decreased NDF digestibility. Fecal NDF-N was higher in tree-supplemented groups ( $P < 0.01$ ) compared with control and increased ( $P < 0.05$ ) with increasing amounts of tree leaves fed. Both apparent and true N digestibility were lower ( $P < 0.05$ ) in *C. calothyrsus*, than in the other tree legume treatments. True N digestibility of 91% for the control was higher ( $P < 0.01$ ) than the tree legume treatments supplemented at both 25 (range, 83–86%) and 50% dietary CP (range, 74–79%). Increasing the amount of tree leaves fed, regardless of tree species, decreased N digestibility in the diets. Higher fecal NDF-N and lower N digestibility in tree leaf supplemented lambs indicated that condensed tannins present in these tree species were binding protein and rendering it less available for digestion. Supplementation with *C. calothyrsus*, which had the highest levels of SPHE and

\* Corresponding author. Present address: E (Kika) de la Garza Institute for Goat Research, Langston University, P.O. Box 730, Langston, OK 73050, USA. Tel.: +1-405-466-3836; fax: +1-405-466-3138  
E-mail address: rmerkel@luresext.edu (R.C. Merkel)

SPRO, affected N utilization more negatively than did supplementation with either *P. falcataria* or *G. sepium*. © 1999 Elsevier Science B.V. All rights reserved.

**Keywords:** *Calliandra calothyrsus*; *Paraserianthes falcataria*; *Gliricidia sepium*; Proanthocyanidins; Daily gain; Digestibility

---

## 1. Introduction

The growth of ruminants in North Sumatra can be greatly improved through feeding locally available concentrate sources, such as palm kernel cake, rice bran, cassava and molasses (Pond et al., 1994; Djajanegara et al., 1996). However, a major constraint in efficiently utilizing these energy sources is the lack of an economical source of crude protein. Tropical tree legumes, when fed as a protein supplement, have been reported to improve animal daily responses (Norton, 1994). For example, *G. sepium* supplemented to a low quality diet resulted in increased dry matter intake, as the amount of supplementation fed increased. The improved intakes resulted in higher dry matter digestibility and higher average daily gains.

Although tropical legume trees are an underutilized source of feed protein, they also contain antinutritional compounds, such as soluble phenolics and tannins, that can adversely influence an animal's performance. Three tree legume species having potential as a source of feed protein are *Calliandra calothyrsus*, *Paraserianthes falcataria* and *Gliricidia sepium* (Ibrahim et al., 1988). Condensed tannins and phenolic compounds, however, have been found in all three, with *C. calothyrsus* having the highest concentrations and *G. sepium*, the lowest (Mahyuddin et al., 1988). The high tannin and soluble phenolic concentrations found in *C. calothyrsus* have been associated with both reduced dry matter intake and digestibility (Merkel et al., 1999) when fed as the sole ration. Woodward and Reed (1989) concluded that the most significant action of condensed tannins in an animal's diet is upon protein utilization by lowering rumen ammonium nitrogen content and decreasing nitrogen digestion.

The objective of this study was to determine the effect of feeding *Calliandra calothyrsus*, *Paraserianthes falcataria* and *Gliricidia sepium*, hereafter referred to as calliandra, falcataria and gliricidia, respectively, as a crude protein supplement to a high energy basal diet for lamb growth, diet digestibility and nitrogen retention. Supplementation was at 25 and 50% of dietary crude protein. These levels were about 15 and 30% of dietary dry matter, and are levels that could be achieved on the farm.

## 2. Materials and methods

### 2.1. General

The experiment was conducted at the Sungai Putih Research and Assessment Installation for Agriculture Technology (RAINAT), Sungai Putih, North Sumatra, Indonesia. The climate and site have been previously described (Merkel et al., 1999). The experiment consisted of a 90-day growth and intake trial, followed by a digestibility and N balance trial. The animal facility has been previously described (Merkel et al., 1999).

Table 1  
Chemical composition of feedstuffs used in ration formulation<sup>a</sup>

Feedstuff	DM (%)	CP (%)	Ca (%)	P (%)	ME (Mcal/g)
Palm kernel cake	95	14.6	0.22	0.52	2.38
Rice bran	90	9.0	0.16	1.40	2.40
Cassava meal	90	1.5	0.25	0.15	3.46
Molasses	75	4.5	0.94	0.11	3.66
Fish meal	90	60.0	6.80	2.7	2.25
Soybean meal	90	44.0	0.30	0.68	3.20
Urea	98	281.0	—	—	—
Limestone	98	—	34.0	—	—
Mineral mix	98	—	19.7	25.0	—

<sup>a</sup> Compiled from Harris et al., 1982; Kearl, 1982; North Carolina State University and North Carolina Department of Agriculture laboratory analyses.

## 2.2. Experimental treatments

Seven treatments were evaluated in both growth and digestibility trials. A concentrate diet consisting of locally available feedstuffs (Table 1) was common to all treatments. The feedstuffs were hand-mixed, sieved through a 0.25 in. (0.64 cm) metal mesh to provide a uniform texture, and fed daily. Six of the treatments evaluated the three tree legumes — falcataria (F), calothyrsus (C), and sepium (G) — as a crude protein (CP) supplement when fed at 25 (F25, C25, and G25) and 50% (F50, C50, and G50) of the total dietary CP. This proportion represented about 15 and 30% of the dietary dry matter. The seventh treatment was the control diet consisting of the perennial grass, *Brachiaria brizantha* (brachiaria), which contained 15% of the dietary dry matter and corresponded to the dietary dry matter provided by the low level of tree leaf supplementation. All diets were formulated to contain 14% CP and 2.5 Mcal/kg of metabolizable energy (Table 2). The source and proportion of the tree legumes and brachiaria for feeding are as previously described (Merkel et al., 1999).

## 2.3. Animals and feeding

Twenty St. Croix × Sumatra crossbred F<sub>1</sub> lambs (CS) and 22 Sumatra lambs (S), 6–19 months old (9.5–14.7 kg) were used in the growth trial. The lambs were stratified by weight and breed, and then randomly assigned to individual pens to the seven experimental diets, providing six lambs per treatment. Breeds were not equally represented in each diet, but the seven diets were evaluated by the two sheep breeds (CS and S), giving 14 treatment groups. All animals were dosed with an anthelmintic at the beginning of the three-week adjustment period, followed by the 90-day growth trial. Three lambs on G25 treatment had to be removed from this study due to inadequate dry matter intake. Animals were weighed weekly with a hanging scale on consecutive days, with the average weekly weight used in a regression equation to calculate average daily gain.

The concentrate ration was weighed for each lamb and fed at 0800 hours and remained in the feed trough until 1400 hours when refusals were collected and weighed. The tree

Table 2

Dry matter composition of seven diets fed to growing ram lambs

Component (%)	Diets <sup>a</sup>						
	B	F25	C25	G25	F50	C50	G50
Forage	15.0	16.0	15.0	15.0	32.0	30.5	29.0
Palm kernel cake	45.0	45.0	45.0	45.0	28.0	25.5	27.7
Rice bran	10.0	14.5	15.0	14.5	10.3	14.7	11.0
Cassava meal	7.7	10.0	10.5	11.0	15.4	15.0	18.0
Molasses	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Urea	0.3	0.5	0.5	0.5	0.3	0.3	0.3
Fish meal	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Limestone	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Mineral mix	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Salt	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Soybean meal	8.0	—	—	—	—	—	—

<sup>a</sup> B: *B. brizantha*; F25, C25 and G25: *P. falcata* (F), *C. calothyrsus* (C), and *G. sepium* (G) fed at 25% of dietary CP; and F50, C50 and G50 fed at 50% of dietary CP.

legume forage was harvested each morning (see Merkel et al., 1999) and fed at 1500 hours. The quantity fed was adjusted at each feeding to balance dry matter intake of each animal, and was left in the feeder until the following morning (0800 hours) when refusals were collected and weighed. The amount of concentrate offered was adjusted daily to provide ad libitum consumption for those animals that consumed all of their forage. It was adjusted downward, however, for lambs that did not consume their forage allotment. This maintained the appropriate balance in concentrate : forage consumption. In addition, each animal was fed 70 g of fresh brachiaria forage three times a week to provide adequate fiber in the diet. The fresh forage was totally consumed.

The digestion trial was conducted using three of the six lambs from the growth trial. The lambs were moved to individual digestion crates for two weeks of adjustment, followed by a five-day total collection period. Lambs were fed, as described above, for the growth trial and the digestion trial conducted as described by Merkel et al. (1999). Animal weights were obtained at the end of the digestion trial.

#### 2.4. Sampling procedure

In the growth trial, concentrates were sampled after mixing, and a composite sample was obtained for the study. All forages were sampled thrice weekly at the time of feeding, with subsamples taken for oven and freeze drying and composited by forage species. Forage refusals were sampled on the same days the 'as-fed' samples were taken and composited by the animals. Because of limited drying facilities, all samples were initially frozen before oven and freeze drying.

In the digestibility trial, concentrates were sampled as noted above, but grass and tree legume forage was sampled daily for both oven and freeze drying. Individual animal concentrate refusals were composited for the collection period and subsampled. Forage refusals composited by the animals for the collection period were frozen for later freeze drying. Unfortunately, those samples had to be discarded because of a power outage,

which resulted in thawing and subsequent mold growth. Consequently, average composition values of the fed material were used as refusal composition values in the digestibility calculations. This was not viewed as a major source of error because refusals were whole leaves and similar to the fed material. Urine and feces were collected daily, as previously described (Merkel et al., 1999), with 5 and 10%, respectively, composited by the animals for the five-day period and frozen for later analyses.

All concentrate, forage and fecal samples to be oven dried were placed in a forced-air oven at 60°C at the research site. Samples for freeze drying were processed in Labconco freeze dryers (Labconco Corp., Kansas City, MO<sup>1</sup>). In preparation for analyses, all dried samples were ground in a Wiley mill to pass through a 1 mm screen, with subsamples taken and ground further in a cyclone mill (Model 3010-030, Udy Corporation, Fort Collins, CO<sup>1</sup>) to pass through a 1 mm screen.

### 2.5. Laboratory analyses

Feeds were analyzed for dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin (LIG), in vitro dry matter disappearance (IVDMD), residual NDF following 48 h in vitro incubation (RNDF), total nitrogen (N) and nitrogen in NDF (NDF-N) and ADF (ADF-N) residues, as previously described (Merkel et al., 1999). Freeze-dried forage samples of fed material were analyzed gravimetrically for soluble phenolics (SPHE), according to Reed et al. (1985), and for soluble and insoluble proanthocyanidins (SPRO, IPRO) using HCl : butanol (Bate-Smith, 1973; Reed et al., 1982). Feces were analyzed for DM, OM, NDF, ADF, LIG, N and NDF-N. Fecal metabolic N was calculated as the difference between fecal NDF-N and total fecal N (Van Soest, 1982). Urine was analyzed for N by Kjeldahl procedure.

### 2.6. Statistical analyses

Data were analyzed as a completely randomized design, using a general linear model procedure of SAS (SAS/STAT, 1988). Non-orthogonal contrasts were employed to compare the animal responses among treatments. Forage chemical composition means were compared using the Waller–Duncan *k*-ratio *t*-test, with *k*-ratio = 100.

## 3. Results and discussion

### 3.1. Growth trial

#### 3.1.1. Average daily gain and feed efficiency

Average daily gain (ADG) was higher ( $P < 0.001$ ) for CS lambs than S lambs, averaging 150 versus 114 g per day (Table 4). While lambs fed the control diet outgained

<sup>1</sup> Mention of trade names, warranty, proprietary products, or vendor does not imply endorsement by any of the supporting agencies of the products named or criticism of similar ones not mentioned. All programs and services by USDA are offered on a non-discriminatory basis.

lambs fed tree leaves at both supplementation levels, increasing the amount of tree leaves fed from 25 to 50% of dietary CP had no significant effect on gain. Lambs receiving calliandra gained faster than those receiving gliricidia ( $P < 0.05$ ). Pond et al. (1994), feeding 70% corn–soybean meal based concentrate and 30% grass, found higher gains for CS and S than those found here, 161 and 125 g per day, respectively. In a second trial, using the same diet, the same authors recorded an ADG of 150 g per day for S lambs. Lambs fed tree leaves at 50% dietary CP had lower ( $P < 0.01$ ) efficiencies of gain (168 g/kg feed) than control lambs (204 g/kg feed).

### 3.1.2. Dry matter intake

Dry matter intake of the total ration ranged from 3.0 to 3.8% of body weight among treatments (Table 4), with no differences found among tree species. Only falcataria showed increased intake when fed at 50 versus 25% dietary crude protein ( $P < 0.10$ ). Increased total intakes due to gliricidia (Norton, 1994) and calliandra (Phiri et al., 1992) supplementation have been recorded, though with lower quality diets than the one fed here. Breed had no effect upon DMI. Whereas supplementing with tree legumes at both 25 and 50% dietary crude protein increased dietary DMI over the control treatment ( $P < 0.05$ ), this higher intake did not lead to increased gains, suggesting that use of the diet was inhibited.

### 3.1.3. Tannin intake

Soluble phenolic intake (Table 5) was not different ( $P > 0.10$ ) between falcataria- and gliricidia-supplemented groups, reflecting similar forage soluble phenolic concentrations. Calliandra, with higher phenolic concentration than the other species, recorded much higher intakes of SPHE.

Because absorbance units were not quantified by weight, due to a lack of standards, the intake values for SPRO and IPRO indicate relative differences between groups and allow intake comparisons to be made. Calliandra had the highest SPRO intake, as expected from its high SPRO concentration. Falcataria-fed lambs showed greater ( $P < 0.05$ ) SPRO intake than gliricidia groups. Insoluble proanthocyanidin intake differed among tree legume species and between supplementation levels. All three tree species had statistically similar concentrations of IPRO, although, in absolute quantities, calliandra at 51 AU per gram of NDF (Table 3), had less than half that of both falcataria and gliricidia, which averaged 120 and 116 AU per gram of NDF, respectively. Higher forage dry matter intake of falcataria than gliricidia led to higher IPRO intake in falcataria-fed lambs.

The literature indicates that increased tannin intake is associated with decreased dry matter intake (Barry and Duncan, 1984; Reed et al., 1990). No intake differences were seen between supplemental levels of gliricidia and calliandra, and intake of falcataria at 50% of dietary crude protein was higher than when fed at the lower level. The high digestibility of the basal concentrate may have negated any deleterious effects of tree legume supplementation upon intake and lower quality diets may be more affected. Further, the levels of tree legume supplementation may have been too low to detect differences. These results indicate, however, that these species may be supplemented to a concentrate diet of up to 30% of dry matter without reducing daily dry matter intake.

Table 3  
Chemical composition and in vitro dry matter disappearance (IVDMD) of seven concentrates and four forages to lambs in the digestibility trial

Feed	Treatment <sup>a</sup>	DM (%)	OM (%)	NDF (%)	ADF (%)	LIG (%)	N (%)	ADF-N (%)	IVDMD (%)	RNDF <sup>b</sup> (%)	SPHE <sup>c</sup> (%)	SPRO <sup>c</sup> (AU gDM <sup>-1</sup> )	I PRO <sup>c</sup> (AU gNDF <sup>-1</sup> )
Concentrates:													
Conc 1	B	90	87.1	43	24	4.4	2.8	0.3	71	19	ND <sup>f</sup>	ND	ND
Conc 2	F25	96	88.0	43	24	4.3	2.7	0.2	68	20	ND	ND	ND
Conc 3	C25	90	87.4	42	24	4.3	2.7	0.2	69	19	ND	ND	ND
Conc 4	G25	90	86.8	43	24	4.5	2.5	0.3	69	21	ND	ND	ND
Conc 5	F50	89	86.1	37	22	4.2	2.3	0.2	69	19	ND	ND	ND
Conc 6	C50	89	86.3	36	20	3.9	2.3	0.2	72	17	ND	ND	ND
Conc 7	G50	90	86.7	36	21	3.9	2.1	0.2	73	17	ND	ND	ND
Forages:													
<i>P. Falcataria</i>	F25, F50	31 b	94.6 b	50 b	33 a	14.7 a	3.4 b	0.8 a	35 c	44 a	5 b	1.4 b	120
<i>C. calothyrsus</i>	C25, C50	36 a	95.3 a	49 b	27 b	12.9 b	3.9 a	0.7 a	22 d	43 a	29 a	8.8 a	51
<i>G. sepium</i>	G25, G50	22 d	92.8 c	45 c	27 b	9.9 c	3.9 a	0.4 b	53 b	29 b	4 b	0.1 b	116
<i>B. brizantha</i>	B	25 c	88.2 d	64 a	35 a	3.8 d	1.7 c	0.1 c	61 a	25 c	ND	ND	ND
MSD <sup>d</sup>		2.0	0.3	3.4	2.4	1.6	0.3	0.1	2.7	3.3	6.2	2.2	–
CV <sup>e</sup>		9.2	0.4	7.7	9.3	18.8	10.0	22.3	7.3	11.1	34.5	43.6	83.5

<sup>a</sup> B: *B. brizantha*; F25, C25 and G25: *P. falcataria* (F), *C. calothyrsus* (C), and *G. sepium* (G) fed at 25% of dietary CP; and F50, C50 and G50 fed at 50% of dietary CP.

<sup>b</sup> Residual NDF on a dry matter basis.

<sup>c</sup> SPHE, soluble phenolics; SPRO, soluble proanthocyanidins; I PRO, insoluble proanthocyanidins in absorbance units (AU) 550 nm.

<sup>d</sup> Minimum significant difference; Waller–Duncan *k*-ratio *t*-test, *k*-ratio = 100. Column means followed by a different letter (a,b,c,d) differ.

<sup>e</sup> Coefficient of variation.

<sup>f</sup> Not determined.

### 3.2. Digestibility trial

#### 3.2.1. DM, NDF and lignin intake

In contrast to the growth trial (Table 4), the DMI during the digestion trial was lower, ranging from 2.4 to 2.8% of body weight. The higher temperatures found in the ground level barn, closer confinement in digestibility crates, more human intrusions for fecal and urine collections, and the sight and smell of ewes passing

Table 4

Average daily gain (ADG), dry matter intake as % body weight (DMI) and feed conversion (g gain/kg feed consumed) in the growth trial for fourteen treatments resulting from combinations of two sheep breeds (CS, S)<sup>a</sup> and seven diets (concentrate plus B, F25, F50, C25, C50, G25 or G50)<sup>b</sup>

Treatment	n	ADG (grams per day)	DMI (%)	Gain/feed (grams per kg)	Ending weight (kg)
CSB	3	182	3.2	217	34
SB	3	122	3.0	191	26
CSF25	2	147	3.3	201	28
SF25	4	101	3.1	185	22
CSC25	2	160	3.6	196	31
SC25	4	124	3.2	172	27
CSG25	2	139	3.2	171	28
SG25	1	113	3.6	182	23
CSF50	5	149	3.5	183	29
SF50	1	121	3.4	177	23
CSC50	3	149	3.8	158	30
SC50	3	115	3.3	156	26
CSG50	2	111	3.3	165	26
SG50	4	108	3.3	168	24
CV <sup>c</sup>		14.2	6.1	13.6	10.5
Breed means:					
CS	19	150	3.4	185	30
S	20	114	3.2	175	25
Contrasts: <sup>d</sup>					
CS vs. S		d	NS	NS	d
25 vs. 50		NS	NS	a	NS
F25 vs. F50		NS	a	NS	NS
C25 vs. C50		NS	NS	a	NS
G25 vs. G50		NS	NS	NS	NS
F vs. C		NS	NS	NS	b
F vs. G		NS	NS	NS	NS
C vs. G		b	NS	NS	b
B vs. 25		b	b	NS	b
B vs. 50		c	c	c	b

<sup>a</sup> CS, St. Croix × Sumatra F<sub>1</sub>; S, Sumatra.

<sup>b</sup> B: *B. brizantha*; F25, C25 and G25: *P. falcata* (F), *C. calothyrsus* (C), and *G. sepium* (G) fed at 25% of dietary CP; and F50, C50 and G50 fed at 50% of dietary CP.

<sup>c</sup> Coefficient of variation.

<sup>d</sup> a,  $P < 0.10$ ; b,  $P < 0.05$ ; c,  $P < 0.01$ ; d,  $P < 0.001$ ; NS, not significant.

Table 5

Daily DM intake from forage (FDM) and total diet (TDM), neutral detergent fiber from forage (FNDF) and total diet (TNDF), lignin from forage (FLIG) and total diet (TLIG), soluble phenolic (SPHE), soluble and insoluble proanthocyanidin (SPRO, IPRO) intakes as well as DM and NDF digestibilities

Treatment <sup>a</sup>	Intakes (g/kg BW/day)									Digestibility (%)	
	FDM	TDM	FNDF	TNDF	FLIG	TLIG	SPHE	SPRO	IPRO	DM	NDF
B	3.37	25.6	2.18	11.3	0.13	1.00	ND <sup>c</sup>	ND	ND	68	57
F25	3.84	25.6	1.91	11.4	0.56	1.50	0.16	0.052	2.15	66	54
C25	3.28	23.7	1.61	10.4	0.43	1.30	0.96	0.290	0.82	64	53
G25	2.94	25.9	1.35	10.9	0.32	1.27	0.12	0.004	1.60	67	53
F50	8.25	26.9	4.11	11.1	1.21	2.00	0.35	0.110	4.60	64	44
C50	7.74	26.8	3.79	10.7	1.00	1.75	2.25	0.680	1.97	63	45
G50	6.73	27.5	3.84	10.7	0.69	1.48	0.28	0.008	3.65	65	46
CV <sup>b</sup>	12.8	10.6	12.5	11.0	12.9	11.5	13.9	14.8	14.7	2.9	7.5
Contrasts: <sup>d</sup>											
25 vs. 50	d	NS	d	NS	d	d	d	d	d	a	d
F25 vs. F50	d	NS	d	NS	d	c	b	b	d	a	c
C25 vs. C50	d	NS	d	NS	d	c	d	d	c	NS	b
G25 vs. G50	d	NS	d	NS	d	NS	a	NS	d	NS	a
F vs. C	NS	NS	NS	NS	c	b	d	d	d	NS	NS
F vs. G	c	NS	d	NS	d	c	NS	d	c	NS	NS
C vs. G	a	NS	b	NS	d	NS	d	d	d	b	NS
B vs. 25	NS	NS	b	NS	d	c	ND	ND	ND	b	NS
B vs. 50	d	NS	d	NS	d	d	ND	ND	ND	c	d

<sup>a</sup> B: *B. brizantha*; F25, F50, C25, C50, G25, G50: *P. falcata* (F), *C. calothyrsus* (C), *G. sepium* (G), each fed at 25 and 50% of dietary crude protein; three lambs per diet.

<sup>b</sup> Coefficient of variation.

<sup>c</sup> Not determined.

<sup>d</sup> a,  $P < 0.10$ ; b,  $P < 0.05$ ; c,  $P < 0.01$ ; d,  $P < 0.001$ ; NS, not significant.

by daily on their way to pasture, increased stress and likely accounts for the decrease in feed consumption.

Examining the intake (g/kg BW/day) of forage DM, NDF and LIG (FDM, FNDF, FLIG) and total intakes (forage plus concentrate) of the same components (TDM, TNDF, TLIG) showed that increasing the amount of tree legumes fed led to predictable increases in the amount of DM, NDF and LIG contributed by the forage (Table 5). Total intakes of DM and NDF, however, did not vary among control and tree legume-supplemented treatments or between the 25 and 50% dietary treatments. Tree legume-supplemented treatments had higher TLIG ( $P < 0.01$ ) than the control group supplemented with brachiaria because of the higher lignin concentrations found in the tree legumes. Both falcata and calliandra fed at 50% dietary CP had higher lignin intakes than did the 25% dietary CP treatments, while gliricidia treatments recorded similar lignin intakes.

### 3.2.2. Dry matter and NDF digestibility

The control treatment showed higher DM digestibility, averaging 68%, than did treatments in which tree leaves were fed at both 25 (mean, 66%;  $P < 0.05$ ) and 50%

dietary CP levels (mean, 64%;  $P < 0.01$ ) (Table 5). Among tree species, only *falcataria* showed further decreases in DM digestibility with increasing levels of tree leaves fed ( $P < 0.10$ ). While NDF digestibility of the 25% dietary CP groups (mean, 53%) was not different from the control (mean, 57%), both were higher ( $P < 0.01$ ) than the 50% dietary CP groups (mean, 45%).

Decreased DM and NDF digestibility in the tree legume-supplemented treatments compared with the control is probably related to both lignin levels and proanthocyanidin action. All three tree species had higher LIG and RNDF concentrations than *brachiaria*, while the concentrate levels were similar (Table 3). The RNDF of a feed is the measure of its indigestibility (Van Soest, 1982) and substituting less digestible, tannin-containing forage for concentrate would decrease dietary digestibility of DM and fiber. It is unclear why increasing the amounts of tree leaves of lower digestibility did not further decrease DM digestibility. When feeding *falcataria* and *calliandra*, SPHE and SPRO intakes more than doubled when increasing from 25 to 50% of dietary CP, but only in *falcataria* was a significant drop in DM digestibility noted. Meanwhile, NDF digestibility was lower in the higher supplemented treatments of all three tree species. Correlation coefficients between total daily intake of forage lignin and NDF digestibility and total daily lignin intake and NDF digestibility were  $-0.877$  ( $P < 0.05$ ) and  $-0.796$  ( $P < 0.10$ ), respectively, for the six tree legume supplemented treatments.

### 3.2.3. Nitrogen intake, excretion and retention

As expected, N intake (Table 6) from concentrate was lower ( $P < 0.05$ ), and forage N intakes higher ( $P < 0.001$ ), for the 50% dietary CP treatments than from both the control and 25% dietary CP treatments. The control treatment, fed *brachiaria*, had the lowest N intake from forage at 57 mg/kg BW/day. Total N intake, however, did not vary among the treatments.

Fecal nitrogen was analyzed for fecal NDF-N and fecal metabolic nitrogen (Van Soest, 1982). Fecal N was higher from lambs supplemented with tree legumes, ( $P < 0.01$ ) and increased with increasing amounts of tree leaves fed ( $P < 0.05$ ). *Calliandra*-fed lambs excreted more ( $P < 0.05$ ) fecal N and NDF-N than *gliricidia*-fed animals with *falcataria* intermediate. *Calliandra* and *gliricidia* fed at 50% dietary CP had lower ( $P < 0.10$ ) excretion of fecal metabolic N than when fed at 25% dietary CP. Reed et al. (1990), studying African browse, reported increased fecal NDF-N values and ascribed it to proanthocyanidins binding irreversibly with protein forming indigestible complexes. Increasing intakes of proanthocyanidins led to increased fecal NDF-N in tree legume fed lambs. Correlation coefficients between total daily intakes of SPRO and SPHE and fecal NDF-N were 0.769 ( $P < 0.10$ ) and 0.782 ( $P < 0.10$ ), respectively, indicating a positive relationship between phenolic and proanthocyanidin intake and fecal NDF-N.

Urinary N excretion was higher ( $P < 0.10$ ) for control lambs than for lambs supplemented with tree legumes, although no difference occurred between treatment levels or among tree species. Condensed tannin intake has been associated with decreased urinary N levels (Waghorn et al., 1987; Reed et al., 1990) due to the reduced availability of tannin–protein complexes for ruminal digestion. Nitrogen retention was higher ( $P < 0.10$ ) in *falcataria*- than *calliandra*-fed lambs, though similar ( $P > 0.10$ ) to *gliricidia*-

Table 6  
Daily nitrogen intake from concentrate (Conc), forage and total diet; daily fecal output of N, NDF-N and fecal metabolic N (Met N) (mg/kg BW/day); urinary N; retained N; and apparent and true N digestibilities for seven diets (concentrate plus B, F25, F50, C25, C50, G25 and G50)<sup>a</sup> fed to ram lambs

Treatment	N intake			Fecal output			Urinary N	Retained N	N digestibility	
	Conc	Forage	Total	N	NDF-N	Met N			Apparent	True
B	618	57	674	244	63	183	104	325	64	91
F25	603	132	734	304	113	192	72	358	59	85
C25	549	129	677	326	111	215	68	284	52	83
G25	584	113	698	301	100	201	77	318	57	86
F50	438	282	720	316	152	163	65	341	56	79
C50	437	302	728	372	192	178	68	298	50	74
G50	421	258	680	293	146	147	86	303	57	78
CV <sup>b</sup>	10.5	13.6	10.9	13.0	17.7	13.9	26.9	15.7	7.0	3.1
Contrasts: <sup>c</sup>										
25 vs. 50	d	d	NS	NS	d	c	NS	NS	NS	d
F25 vs. F50	c	d	NS	NS	b	NS	NS	NS	NS	b
C25 vs. C50	b	d	NS	NS	d	a	NS	NS	NS	d
G25 vs. G50	c	d	NS	NS	b	b	NS	NS	NS	c
F vs. C	NS	NS	NS	NS	NS	NS	NS	a	c	b
F vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C vs. G	NS	a	NS	b	b	NS	NS	NS	b	b
B vs. 25	NS	c	NS	b	c	NS	b	NS	c	c
B vs. 50	c	d	NS	c	d	NS	b	NS	c	d

<sup>a</sup> B: *B. brizantha*; F25, F50, C25, C50, G25, G50: *P. falcata* (F), *C. calothyrsus* (C), *G. sepium* (G), each fed at 25 and 50% of dietary crude protein; three lambs per diet.

<sup>b</sup> Coefficient of variation.

<sup>c</sup> a,  $P < 0.10$ ; b,  $P < 0.05$ ; c,  $P < 0.01$ ; d,  $P < 0.001$ ; NS, not significant.

fed animals. Retained N has been reported to both increase (Barry et al., 1986) and decrease (Reed et al., 1990) in animals fed tannin containing diets.

#### 3.2.4. Nitrogen digestibility

The brachiaria supplemented control had higher apparent and true N digestibility than both the 25 and 50% dietary CP groups ( $P < 0.01$ ). The control treatment showed a true N digestibility of 91% (Table 6), while the tree legume supplemented treatments showed decreased true N digestibility from the 83–86%, found in 25% dietary CP treatment, to 74–79% in the 50% dietary CP treatment ( $P < 0.001$ ). Whereas falcataria and gliricidia treatments were not different in N digestibilities, calliandra-fed lambs recorded the lowest ( $P < 0.05$ ) apparent and true N digestibilities of 50 and 74%, respectively.

Nitrogen digestibility is generally decreased in tanniferous diets (Barry and Manley, 1984; Waghorn et al., 1987; Reed et al., 1990), indicating that condensed tannins bind protein, making it less available for digestion. True N digestibility, calculated by correcting apparent N digestibility for fecal NDF-N, was reduced when tree legumes were fed, and was reduced further as dietary CP from tree legumes increased from 25 to 50%. Increased fecal NDF-N concentrations, noted in tree legume treatments (Table 6), were attributed to the binding of proteins by proanthocyanidins, leading to decreased true N digestibility. The source of N in fecal NDF-N in tanniferous diets, whether feed N or endogenous N, has been previously discussed (Merkel et al., 1999). In this experiment, the high N concentrations and digestibility of concentrates, coupled with the low levels of tree legumes fed, may have reduced the magnitude of the tannin effects noted. Lower quality diets may be more affected by dietary condensed tannins.

## 4. Conclusions

During the growth and intake trial, supplementing concentrate diets with tree legumes at 15 or 30% of dry matter increased total dry matter intake over control. Although supplemented lambs experienced decreased growth rate compared with the control, increasing the amount of tree leaves fed did not result in further decreases in ADG. Tree legume supplementation decreased both DM and N digestibility, compared with the control, with true N digestibility lower for the 50% dietary CP than for the 25% dietary CP treatments. Supplementing with calliandra, having the highest phenolic and proanthocyanidin concentrations, resulted in lower N digestibility and higher fecal N than falcataria and gliricidia supplementation.

In this experiment, phenolic compounds and proanthocyanidins decreased N digestibility and increased fecal N and fecal NDF-N. Whether the increased fecal NDF-N was due to feed or endogenous proteins (such as salivary proteins) irreversibly bound by tannins during mastication or in the rumen, or whether a portion of fecal NDF-N represents tannin–protein complexes formed in the lower digestive tract, cannot be determined from the present study, and requires further investigation. The decreased N digestibility and ADG reported in this study suggests tree legumes are

not suitable for supplementing high quality diets. The use of these tree legume species would be better suited as supplements to lower quality forage diets where total N intake may be limiting.

## Acknowledgements

This research was supported by the USAID funded Small Ruminant Collaborative Research Support Program, the Agency for Agricultural Research and Development of Indonesia, North Carolina State University and USDA-ARS Raleigh, NC.

## References

- Barry, T.N., Manley, T.R., 1984. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep. 2. Quantitative digestion of carbohydrates and proteins. *Br. J. Nutr.* 51, 493–504.
- Barry, T.N., Duncan, S.J., 1984. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep. 1. Voluntary intake. *Br. J. Nutr.* 51, 485–491.
- Barry, T.N., Manley, T.R., Duncan, S.J., 1986. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep. *Br. J. Nutr.* 55, 123–137.
- Bate-Smith, E.C., 1973. Haemanalysis of tannins: the concept of relative astringency. *Phytochemistry* 12, 907–912.
- Djajanegara, A., Pond, K.R., Batubara, L.P., Merkel, R.C., 1996. Supplementation strategies for small ruminants in low and high input production systems. In: Merkel, R.C., Soedjana, T.S., Subandriyo (Eds.), *Small Ruminant Production: Recommendations for Southeast Asia*. Small Ruminant Collaborative Research Support Program, University of California, Davis, CA, pp. 35–51.
- Harris, L.E., Leche, T.F., Kearn, L.C., Fonnesebeck, P.V., Lloyd, H., 1982. *Central and Southeast Asia Tables of Feed Composition*. International Feedstuffs Institute, Utah State University, Logan, UT.
- Ibrahim, T.M., Palmer, B., Boer, M., Sanchez, M., 1988. Shrub legume potential for integrated farming systems in northern Sumatra — nutritional constraints and palatability. Maximising Livestock Productivity. In: *Proc. 11th Annual Conf. Malaysian Society of Animal Production*. MSAP, Serdang, Selangor, Malaysia, pp. 128–132.
- Kearn, L.C., 1982. *Nutrient Requirements of Ruminants in Developing Countries*. International Feedstuffs Institute, Utah State University, Logan, UT.
- Mahyuddin, P., Little, D.A., Lowry, J.B., 1988. Drying treatment drastically affects feed evaluation and feed quality with certain tropical legume species. *Anim. Feed Sci. Tech.* 22, 69–78.
- Merkel, R.C., Pond, K.R., Burns, J.C., Fisher, D.S., 1999. Intake, digestibility and nitrogen utilization of three tropical tree legumes I. As sole feeds compared to *Asystasia intrusa* and *Brachiaria brizantha*. *Anim. Feed Sci. Tech.* 82, 91–106.
- Norton, B.W., 1994. Tree legumes as dietary supplements for ruminants. In: Gutteridge, R.C., Shelton, H.M. (Eds.), *Forage Tree Legumes in Tropical Agriculture*. CAB International, UK, pp. 192–201.
- Phiri, D.M., Coulman, B., Stepler, H.A., Kamara, C.S., Kwesiga, F., 1992. The effect of browse supplementation on maize husk utilization by goats. *Agroforestry Syst.* 17, 153–158.
- Pond, K.R., Sanchez, M.D., Horne, P.M., Merkel, R.C., Batubara, L.P., Ibrahim, T., Ginting, S.P., Burns, J.C., Fisher, D.S., 1994. Improving feeding strategies for small ruminants in the Asian region. In: Subandriyo, Gatenby, R.M. (Eds.), *Strategic Development for Small Ruminant Production in Asia and the Pacific*. *Proc. Symp. held in conjunction with the 7th Australian Asian Animal Production Animal Science Congress*, Small Ruminant Collaborative Research Support Program, University of California Davis, Davis, CA, USA, pp. 77–97.
- Reed, J.D., Soller, H., Woodward, A., 1990. Fodder tree and straw diets for sheep: intake, growth, digestibility and the effects of phenolics on nitrogen utilisation. *Anim. Feed Sci. Tech.* 30, 39–50.

- Reed, J.D., Horvath, P.J., Allen, M.S., Van Soest, P.J., 1985. Gravimetric determination of soluble phenolics including tannins from leaves by precipitation with trivalent ytterbium. *J. Sci. Food Agric.* 36, 255–266.
- Reed, J.D., McDowell, R.E., Van Soest, P.J., Horvath, P.J., 1982. Condensed tannins: a factor limiting the use of cassava forage. *J. Sci. Food Agric.* 33, 213–220.
- SAS/STAT, 1988. User's Guide, 6.03 ed., SAS Institute, Inc., Cary, NC.
- Van Soest, P.J., 1982. *Nutritional Ecology of the Ruminant*. O&B Books, Inc., Corvallis, OR, 374 p.
- Waghorn, G.C., Ulyatt, M.J., John, A., Fisher, M.T., 1987. The effect of condensed tannins on site of digestion of amino acids and other nutrients in sheep fed on *Lotus corniculatus* L. *Br. J. Nutr.* 57, 115–126.
- Woodward, A., Reed, J.D., 1989. The influence of polyphenolics on the nutritive value of browse: a summary of research conducted at ILCA. *ILCA Bull.* 35, 2–11.